Operational and Technical Updates to the Object Reentry Survival Analysis Tool

NASA Orbital Debris Program Office

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Agenda

- ORSAT History
- Model Updates
- AutoORSAT
- Satellite Test Case
- Conclusions
- Future Work

ORSAT

- **Reentry risk assessments are required for all NASA missions**
  - For <u>uncontrolled</u> reentry, the risk of human casualty from surviving debris shall not exceed 1 in 10,000 (NASA Standard 8719.14A)

- **Object Reentry Survival Analysis Tool (ORSAT) is a high fidelity reentry model developed/maintained by the ODPO to support NASA missions**

Delta II propellant tank (Georgetown, TX, 1997)

Titanium casting of STAR-48B SRM (Saudi Arabia, 2001)

Titanium casting of STAR-48B SRM (Argentina, 2004)

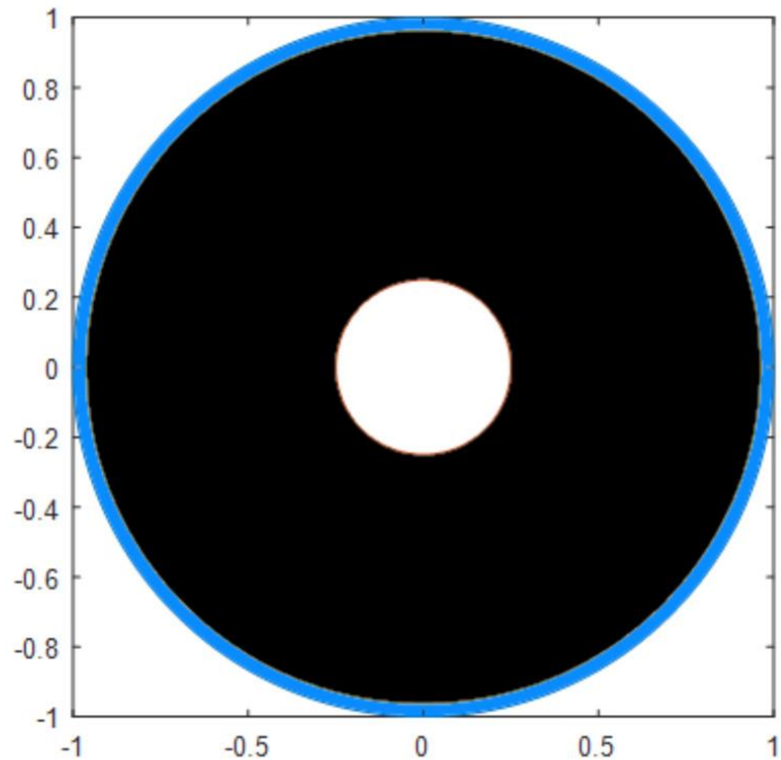
All photos courtesy The Aerospace Corporation

ORSAT History

- **Originally developed in 1994 (version 4.0) to estimate DCA for reentering satellites**
- **Version 5.X developed from 1999-2003**
- **Version 6.0 complete in 2005**
- **Version 6.1 complete in 2008**
- **Version 6.2 and 6.2.1 developed 2017-2019**

Model Updates (1/5)

- **CFRP and GFRP**
  - Previous models assumed no residual strength existed in FRP
  - Tests conducted by ODPO and others indicate that survivability is much higher [1-7]
  - Examples in the media of COPV found on the ground after reentries of spacecraft and upper stages [8-10]
  - "Two-material model" proposed in [7]
    - **If material > 1mm thick, assume fiber fraction will survive to ground**

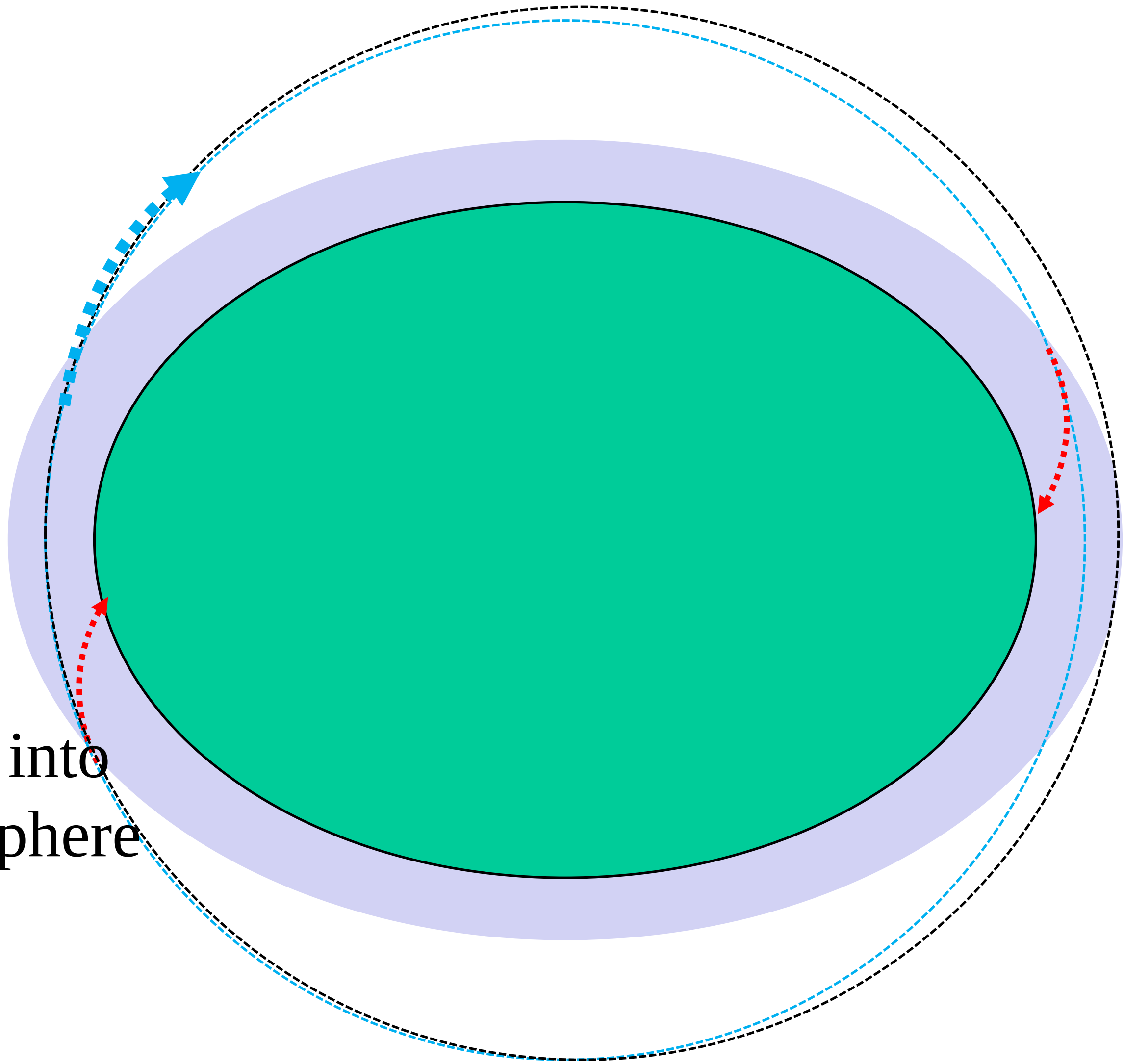


The Basic Effect:
(and why it precedes the nodal crossing)

Atmosphere "falls away" faster than decay rate for most objects that survive passage through the "wall of air".

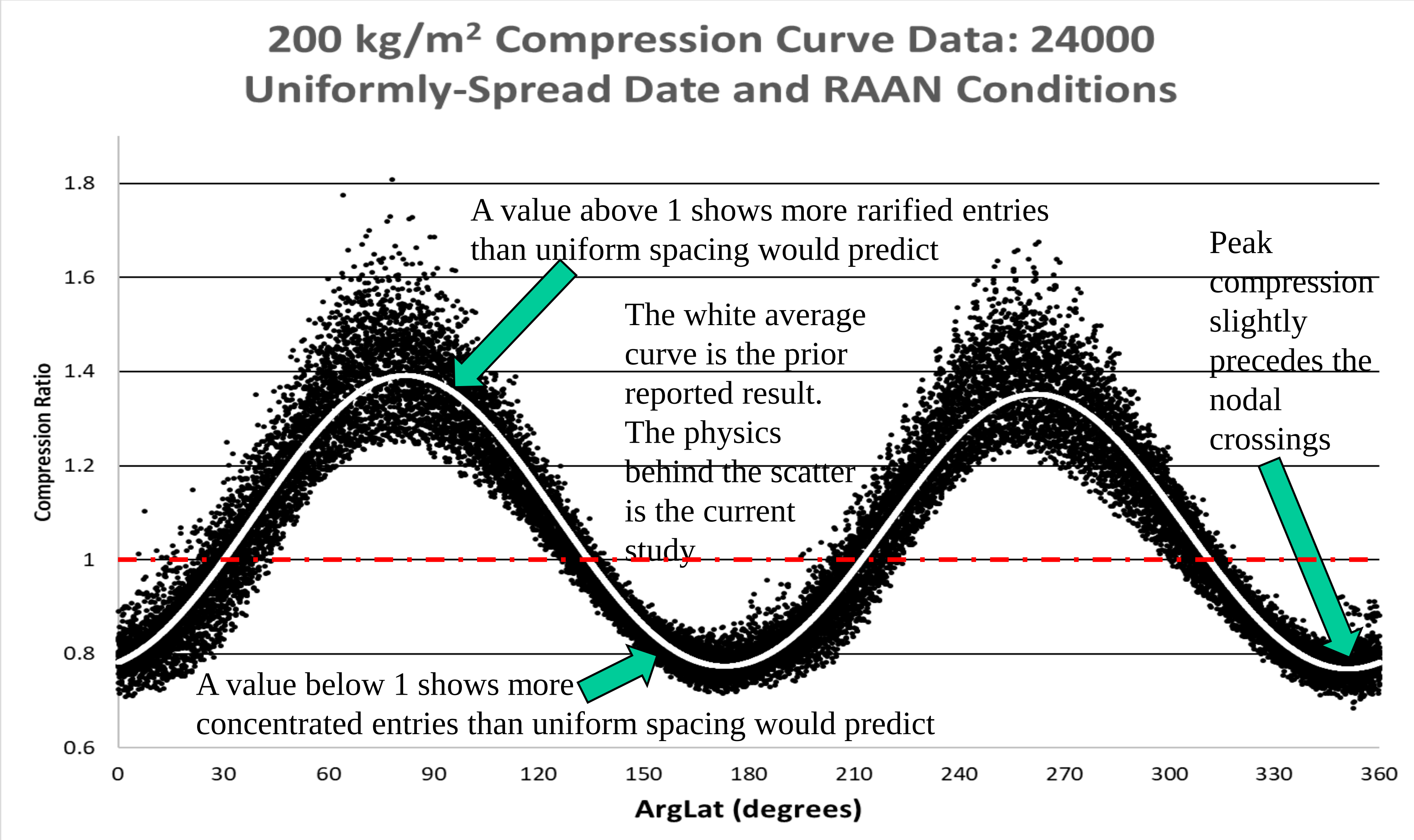
∴

Unlikely to decay in next ¼ orbit



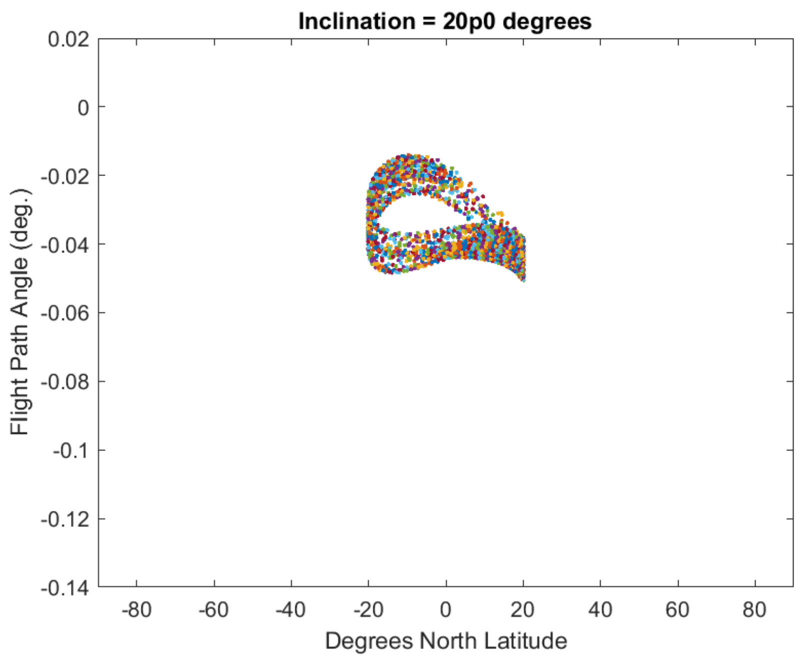
Objects that survive the previous pass have perigee near equator, and rapidly-rising density on the approach

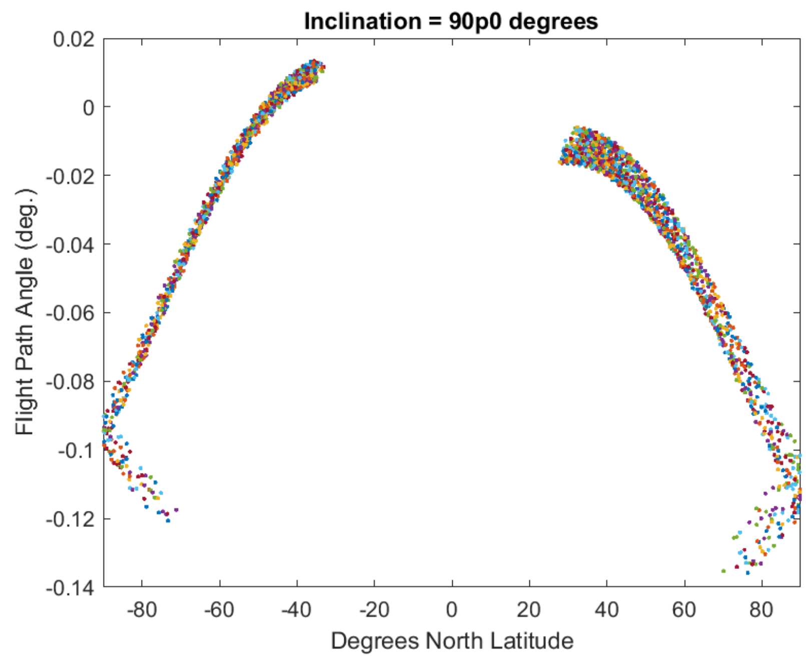
When Ratio'ed to Uniform Spacing, the Spacings of Entry ArgLats Make a "Compression Curve"



Model Updates (2/5)

- **Entry Conditions**
  - Research over past 15-20 years indicates that reentry is not equally likely in time around an orbit (“latitude bias”) [11-16]
  - This bias also creates a bias in conditions at entry interface [17]
  - Effect is not same with varying inclination (or season, or beta) [18]





Model Updates (3/5)

- **Breakup altitude**
  - "Standard" ORSAT assumption is that spacecraft and rocket bodies breakup at 78 km (42 nmi) altitude, based on an Aerospace report [19]
  - Same report suggests that catastrophic breakup occurs when surface radiative equilibrium temperature reaches melting point of structure
  - New ORSAT functionality allows for computation of breakup altitude based on this criterion for each set of entry conditions
  - Objects may now breakup >78km (CubeSats), others lower (steel frames)

Model Updates (4/5)

- **Radiation models**
  – ORSAT 6.0 used “Jones-Park” [20]

  – ORSAT 6.1 added both “Tauber-Sutton” [21] and the program QRAD [22-23]

  – All these models produce minimal effects on entries from circular LEO

Model Updates (5/5)

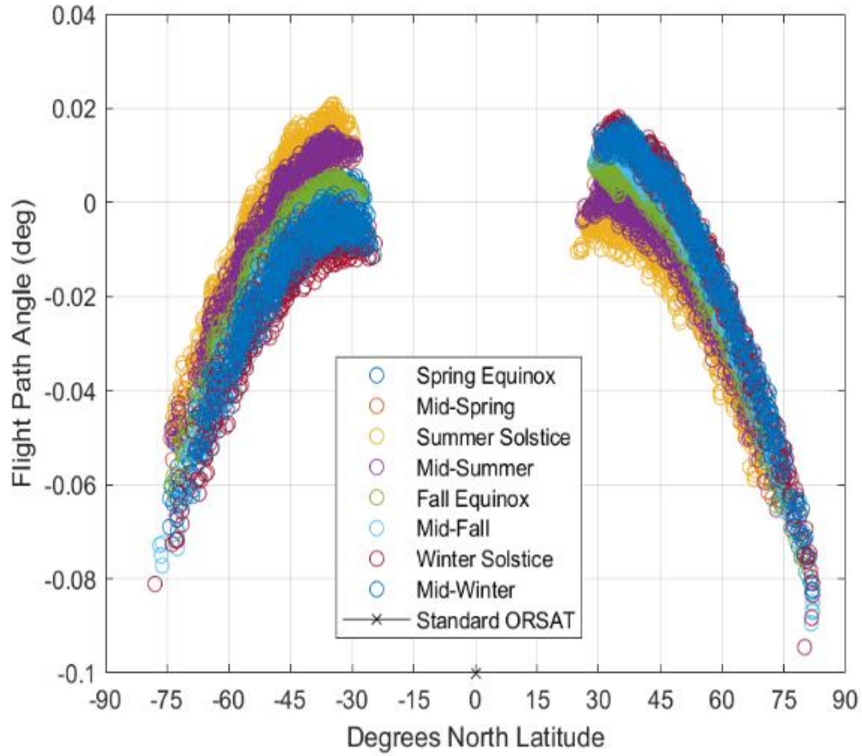
- **Atmosphere model**
  - MSISe-90 was upgraded to NRLMSISE-00 for analysis of controlled entries
- **DCA Update**
  - New model only requires area of object (previous Opiela-Matney model required both area and perimeter [24])
  - RMSE 1% better with new model
- **Source code**
  - Upgraded from F77 to F95
  - Removed parametric study functionality from within ORSAT proper
  - Improved file IO – new “speed mode”

AutoORSAT

- **Python wrapper developed by Greene and Smith [24]**
- **Improved parametric study capability**
  - ORSAT internal function could only do univariate studies
  - Parallel processing
- **Allows simplification of ORSAT code**
  - Use Fortran for heavy lifting, python for “accounting”
- **Combined with computer cluster, >100K runs per hour**
  - Cf. ORSAT 6.0 – 1 run in ~3-6 hours

Satellite Test Case (1/)

- **1100 kg S/C**
  - 150 unique components
- **98.0° inclination**
- **8640 trajectories simulated in GMAT to generate the entry conditions**
  - Varying time of year, RAAN, dithered BC
- **"Standard" ORSAT analysis for comparison**

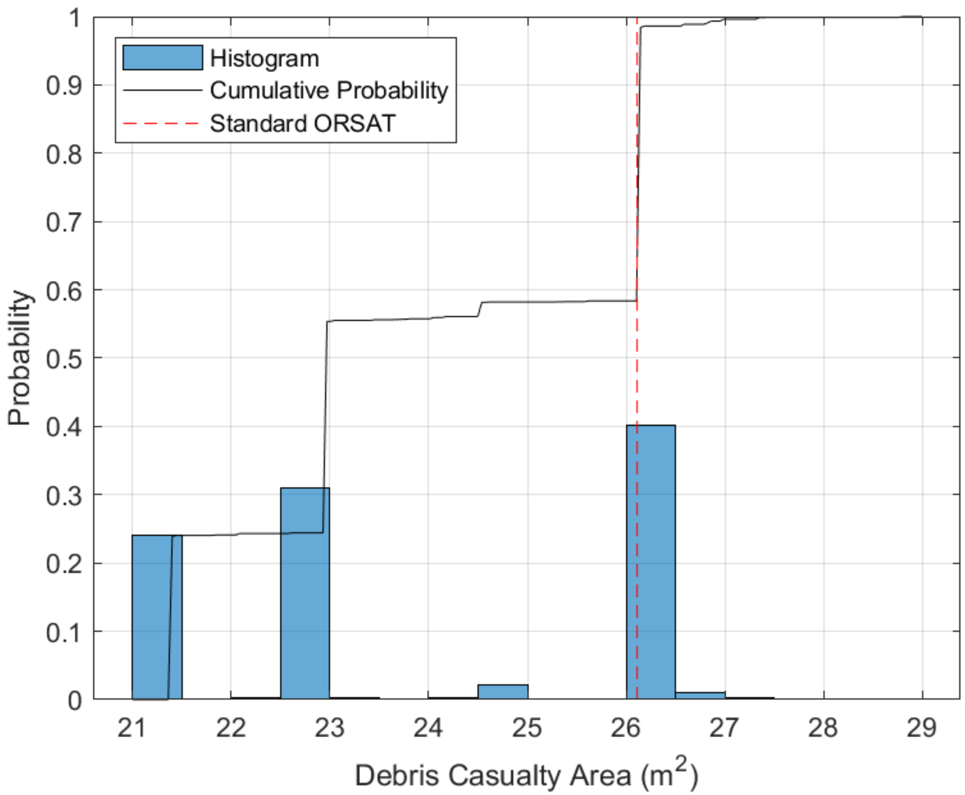


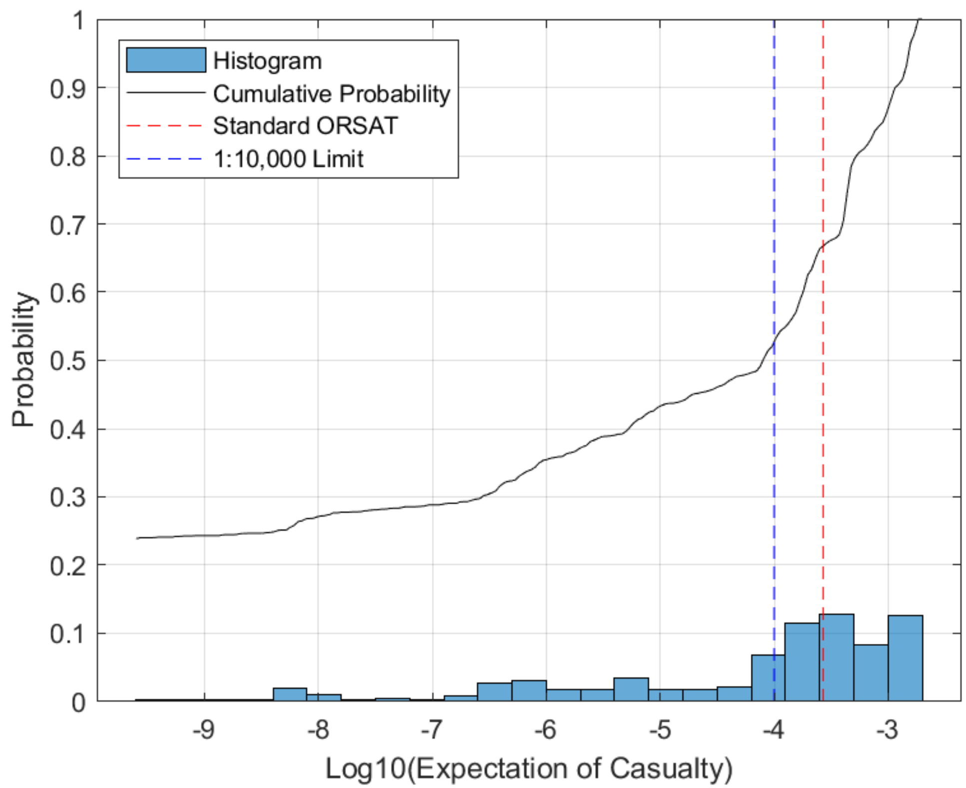
Satellite Test Case (2/)

- **STD ORSAT**
  - 43 surviving components
  - 26 m^2 DCA
  - Ec 1:2700 (using equal temporal likelihood-based population density)

- **AutoORSAT**
  - DCA between 21-29 m^2, depending on conditions
  - Ec depends on where objects land (latitude binning)
  - Average Ec 1:3300
  - Median Ec better than 1:10K (Compliant?)
  - Worst Ec ~1:500

Satellite Test Case (3/)





Conclusions

- **ORSAT 6.2.1 up to 100x faster than v6.0 (single-thread)**
- **AutoORSAT allows for significant exploration of parametric space**
- **Simplification and update allows for faster development going forward and more robust code**

Future Work

- **Design-for-demise (D4D)**
  - Sensitivity to breakup altitude (see Lips [25])
- **Statistics!**
  - Ability to quickly see effects of each parameter (which to ignore and which to refocus on)
- **Improving FRP ablation/demise models**
- **Hollow object modeling**
  - Currently all objects treated as solid, but with less area if hollow
  - New models for transitional flow being developed (see Marichalar [26])

Questions

Thanks for your time!

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8. https://www.campograndenews.com.br/cidades/objeto-que-caiu-em-chacara-e-tanque-de-combustivelestrangeiro-diz-aeb
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14. 7th ESDC – “Fast Re-Entry Deorbitation with Acceptable Risk Level”
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16. 4th IAASS – “Statistical Issues for Uncontrolled Reentry Hazards: Empirical Tests of the Predicted Footprint for Uncontrolled Satellite Reentry Hazards”
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21. Tauber and Sutton. "Stagnation-Point Radiative Heating Relations for Earth and Mars Entries"
22. Page et al. "Radiative Transport in Inviscid Nonadiabatic Stagnation-Region Shock Layers", 1968
23. JSC-26059 – "User's Manual for QRAD Entry Radiation Program"
24. 1st IOC – "Development and Analysis of the Automated Object Reentry Survival Analysis Tool's Parametric Study Wrapper
25. 10th IAASS – "Probabilistic Casualty Risk Assessment and Labeling for the Re-Entry of Spacecraft Components"
26. 1st IOC – "Estimating Drag and Heating Coefficients for Hollow Reentry Objects in Transitional Flow Using DSMC"